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Karem Hafsi, Denis Genon-Catalot, Thanh-Kha Tran, Hamed Yahoui,  
Stephane Renouard

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# News challenges and protocols for DC bus for Smart Buildings

1<sup>st</sup> Karem Hafsi  
 Univ. Grenoble Alpes, LCIS  
 Energie IP  
 Valence, FRANCE  
 karem.hafsi@energie-ip.com

2<sup>nd</sup> Tran Thanh Kha  
 Ampere Laboratory  
 Claude Bernard University Lyon 1  
 Lyon, FRANCE  
 thanh-kha.tran@univ-lyon1.fr

3<sup>rd</sup> Denis Genon-Catalot  
 Univ. Grenoble Alpes, LCIS  
 Valence, FRANCE  
 denis.genon-catalot@lcis.grenoble-inp.fr

4<sup>th</sup> Hamed Yahoui  
 Ampere Laboratory  
 Claude Bernard University Lyon 1  
 Lyon, FRANCE  
 hamed.yahoui@univ-lyon1.fr

5<sup>th</sup> Stéphane Renouard  
 Energie IP  
 rue du Château d'Eau,  
 75010 Paris, FRANCE  
 Stéphane.Renouard@energie-ip.com

**Abstract**—This paper present news trends for electric DC microgrids for smart Homes and smart cities. With the emergence of the renewable energies, the DC bus could optimize electricity power efficiency for smart home (green home). Since the initial choice for alternative current transportation in 1880, the electrical architecture distributions haven't been change with one direction distribution to the consumers through high voltage lines. But AC power distribution therefore is so wasteful due to number of converters AC/AC and AC/DC with consequent energy losses (15% energy per converter). Nowadays most of renewable energy sources as solar panel are DC and all modern appliances are also DC powered (LED lighting, IT, electric car ..). We propose a smart DC grid distribution architecture for smart homes based on 2 voltages levels 48 VDC (Power over Ethernet) and 380 to 400 HVDC bus to improve electrical efficiency.

Under the scope of ANR-C3μ project we present a microgrid DC bus with distributed control command for optimal energy resources management based on self-consumption and peak shaving for the grid. For data exchanges we will use Power Line Communication (PLC) now widely used in wide range of AC application (IP over AC) for the DC line and to pilot the DC microgrid. With the expérimental results feedback we could analyze the communications performances and the design for a microgrid control/command system in smart building applications.

**Index Terms**—Smart building,, Smart grid, DC Bus, PoE

## INTRODUCTION

Since renewable energies electrical rising for production, old paradigm for electrical distribution start to change. Electrical production and distribution is still AC but all of electronic devices, electrical véhicule are DC. We introduce in the ANR-C3μ project a DC smart grid design with decentralized architecture with PLC technology communication (Fig. 1).

### I. BACK TO DC ARCHITECTURE DISTRIBUTION

Over the last decade, most of the publications were presenting AC microgrid architectures [1]. Due to the Point of

Institute of Engineering Univ. Grenoble Alpes.

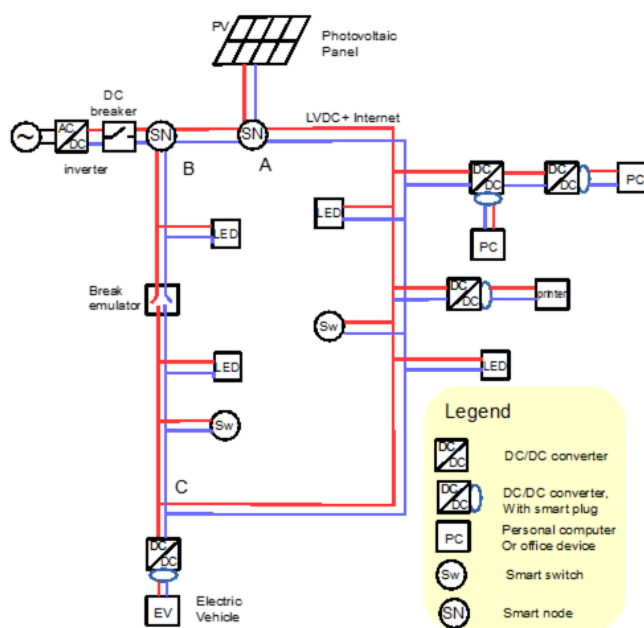


Fig. 1. New architecture based on 380V DC bus

Common Coupling (PCC) the AC microgrids have to deal with phase and frequency stabilization. Actually from solar pannel number of inverter (DC/AC and AC/DC) are inline to deliver DC current for users applications, but each inverter could not reach more than than 90% efficiency. From the grid, the French Energy Regulation (ADEME) advise that due to the line transfert from the production electric area, the efficiency for electricity is just above 50% ! In order to improve efficiency we propose to create a microgrid with production and energy storage for the local consuption. This microgrid is composed of intelligent nodes to distribute energy resources connected to local renewable production or to the grid if needed. These

smart nodes connect to DC bus communicate each other to ensure energy resources management. According to customers needs, This DC micro-grid could connect to the grid in order to buy or sell energy. Many energetic scenarii could be deployed: demande/reponse from the grid, grid pic shaving, energy transfert from solar panels to car battery charging and acception or rejection of new electric dispatching in order to deploy meshed architecture.

As present in Fig 1. the microgrid include :

- A connection to AC-grid, with a bi-directional AC/DC converter. The module could rectify (AC-DC) from the AC-grid to the DC-grid and invert (DC/AC) extra power from DC microgrid sources to AC grid.
- Energy sources as solar panels, batteries or DC generators.
- An Electric Vehicle (EV) plugged to the DC Microgrid.
- Energy storage (batteries or super-capacitors).
- Smart Node : bi-directional power controlflow and current protection).

Our architecture is a decentralized. The control / command is supported by each network smart node. Each smartnode distribute power informations (consumption or production) to other network nodes in order network expandable boundless on the numbers of branches and nodes. In order to reduce the communication cables, we propose within the ANR-C3μ project to evaluate communication over 380 HVVDC lines. Nice idea but there are no specifications for data access on 380V HVDC bus compared to various access protocols over AC network! From existing AC technology state of art, we have decided to evaluate Power Line Communication technology used from AC network (G3-PLC) and a protocol issue from automotive architecture and used in Batteries Managed Systems (BMS-CAN).

For AC protocols after the first anayse, we decided to eliminat Hig-speed PLC protocols that require sophisticated components and wide bandwidth to ensure robustness face to disturbances. We have found that high-speed PLC significantly delayed transmission (up to 500 ms) due to processing and interpreting preambles with complex error correction management. From AC PLC standards, we reduce our choice to protocols with limited data rates that can be used for this project (Table 1 ):

TABLE I  
PLC STANDARDS LOW BITRATE

Standard	Technology	Band Occupied	Max data rate range
PLC G3	OFDM	35 - 90 kHz	33.4 kbps
PRIME	OFDM	42 - 90 kHz	128.6 kbps
G1	SFSK	60- 76 KHz	1.2- 2.4 kbps
P1901.2	OFDM	35-450 kHz	34 -234 Kbps
PLCLite	OFDM	42- 90 kHz	2.4 - 21 kbps
Green PHY	OFDM	120-400 KHz	250Kbps - 3.8Mbps

## II. FRENCH POWER SUPPLIER PROTOCOL

For the new electrical smart metering generation the French power supplier Enerdis have start experimentation with re-

duced databit protocol (2400bps) based on G1-PLC technology (300.000 electical metering over Lyon and Tours cities). With the field experimentation feedback informations they started deploying after 2015 new electrical metering protocol with G3-PLC technology conforms to IEEE P1901.2 Standard based on OFDM technology to achieve bit rate up 300 Kbps. This new protocol brings robustness, speed and range required by networks with large scale for at least 17 millions electrical meters in the french land.

### A. G3-PLC's features

G3-PLC technology use advanced broadband communication techniques using OFDM (Orthogonal frequency division multiplexing) an advanced channel coding modulation. This combination promotes robust carrier currents communication on noisy channel..

The selected bandwidth (CENELEC / FCC / ..) is divided into several subchannels, which can be seen as much independants modulators with differents orthogonal (non-interfering) modulation . Convolution encodings and Reed-Solomon provide bits redundancy allowing receiver to retrieve the bits lost due to background and impulse noise. The OFDM modulation is generated by the execution of complex value signal points (Inverse FFT) produced by differential coded phase modulation, supported by subcarriers. We will use standards in conformity with worldwide organizations regulations like CENELEC, ARIB and FCC :

- Frequency bandwidth (from 10 to 487.5 KHZ) (Table II)
- Modulations schemes 8PSK, QPSK, BPSK and Robust.
- An adaptive tone mapping (subchannel selection) to optimize bandwidth use.
- Two levels of FEC (anticipated error correction) for robust communication on the channels when the environment getting worse.
- IPv6 protocol support, for systems electrical energy management systems based on the Internet Protocol.
- Enhanced CSMA / CA protocols, ARQ (automatic request Repetition) and MRP (Meshed Network Routing) to support all the current services of MAC layer for various network topologies.
- A fast CMM authentication coprocessor with AES-128 encryption, to increase the data security .

### B. Experimental transmission time measurements

Within G3 protocol, two types of frames are recognized by the physical layer (difference at the level of the FCH according to the robust mode or not).This preamble consists of eight symbols SYNC followed by one and half symbol without cyclic prefix between adjacent symbols. The preamble is followed by 13 data symbols allocated to the FCH (Frame Control Header). The FCH has important control information required to decode the frame.

The theoretical duration of a PHY frame is calculated using of the following equation:

$$T_{Frame} = ((N_s + N_{FCH}) \times (N_{CP} + N - NO) + (N_{pre} \times N)) / F_s$$

TABLE II  
FREQUENCIES BANDS SUPPORTED BY G3-PLC

Frequency bande	Robuste baud-rate(bps)	DBPSK baud-rate(bps)	DQPSK baud-rate(bps)	D8PSK baud-rate(bps)	Max D8PSK baud-rate(bps)
CENELEC A(36 KHz - 91KHz)	4.5	14.6	29.3	43.9	46.0
FCC (150 KHz - 487.5KHz)	21.0	62.3	124.5	186.8	234.3
FCC (10KHz - 487.5KHz)	38.0	75.1	150.3	225.4	298.2

$N_s$  is the number of symbols for the data (parameter varies between 12 and 256), the other parameters are defined in table III.

TABLE III  
SYSTEM'S PARAMETERS

Number of FFT points	$N=256$
Number of overlapping samples	$N_o=8$
Number of cyclic prefix samples	$N_{CP}=30$
Number of FCH symbols	$N_{FCH}=13$
Sampling frequency	$F_s=0.4\text{MHz}$
Number of symbols in the preamble	$N_{pre}=9.5$

### C. OSI Model

As illustrated in Figure 2, G3-PLC protocol integrates IPv6, the new generation of IP, which opens up broadly the range of potential applications and services in PLC.

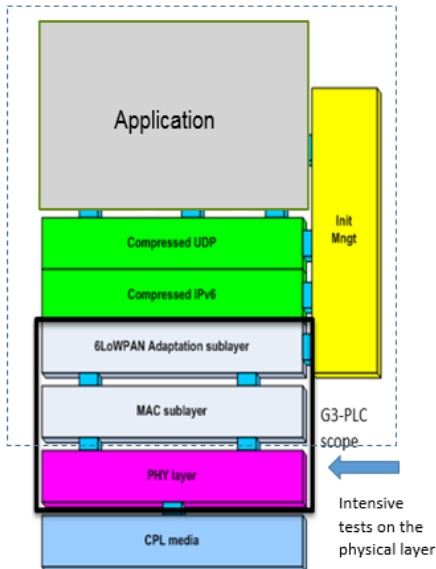


Fig. 2. OSI model of G3-PLC protocol [6]

To allow a good interoperability between IPv6 and the MAC layer, the sub-layer 6LoWPAN is integrated between the IP and the MAC layer in order to reduce the minimum MTU size of IPV6 from 1280 bytes to 127 bytes by using a compression and fragmentation mechanisms. The application layer includes two large classes applications : applications based on DLMS / COSEM (energy metering) and applications providing network management.

### III. G3-PLC STACK TESTS

In order to test the G3-PLC protocol over DC, we have created a reduced network with 2 nodes (ATSAM4C Atmel-Microchip) communicate with each other on the DC bus. Each node is connect to PC in order to dynamically configure the G3-PLC and get the tests results.



Fig. 3. Tests bench of G3-PLC protocol

To dynamically set up the G3-PLC operating parameters, we have developed software tools to configure the G3-PLC software stack and test communications between nodes of our Smart-Grid network. This software is able to set up these functions :

- Configuration of network node's identifier,
- Configuration of communication modulation type (QPSK, BPSK or Robust),
- Configuration of frequency band (CENELEC, ARIB or FCC),
- Configuration of frequency mask used for data transfer (tone mapping),
- Configuration of subcarriers for data transfer.

#### A. Experimental transmission time tests

The communication scheme is presented figure 4 :

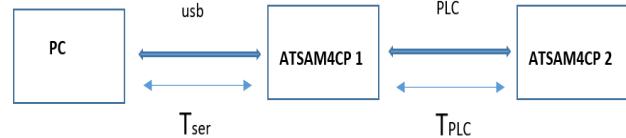


Fig. 4. G3-PLC protocol communication tests

We performed all the tests directly on the physical layer of the G3-PLC protocol in order to determine the latency and the minimum transmission time of one data byte between two

nodes. To do this, we implemented an algorithm to calculate the communication maximum latency in order to determine the exact time provided by a frame starting from the node A and arriving at the node B located 2 m wired distance.

The minimum transmission time of a single byte on the PLC network depends on the chosen type of modulation (BPSK, QPSK or Robust) it also depends on the tone mapping performed and the number of subcarriers chosen for data transmission. All tests were performed for the Cenelec group. As can be seen in the measurement diagrams, from the offset point (delay), the transmission time increases linearly with the number of data bytes transfer over the network.

The evolution of the transmission time according to the number of bytes for transmission in QPSK mode is given in the figure below:

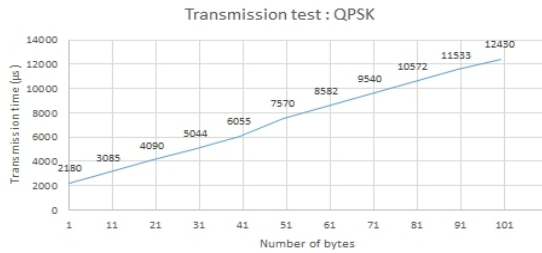


Fig. 5. baud-rate for QPSK transmission

- Tonemap

The Tonemap is a tone card setting. The value '0' set up the remote transmitter to send fictitious data on the corresponding subcarrier. The value '1' indicates that valid data must be placed on the corresponding subcarrier. We have embedded in the test software a configuration part of this parameter and in the figure below, we can see the influence of this parameter on the BPSK mode rate (Figure 6).

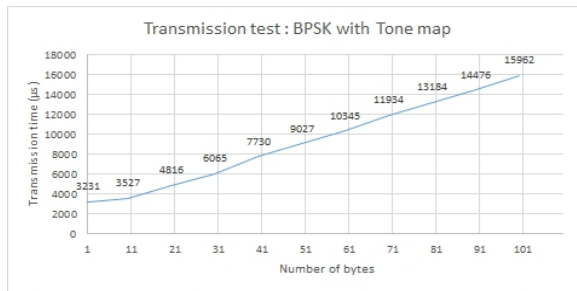


Fig. 6. Influence of Tonemap on BPSK transmission

If we configure the 'Robust' transmission mode, the delay and time increase drastically (Figure 7).

At the end of these tests, we found that the G3 protocol designed for long distances with a robust coding system introduced low data rates and excessive delays in your DC micro-array applications. We are starting to study other protocols used in the automotive sector since new electric vehicles of the Tesla or BMW I series are powered by 365 HVDC high

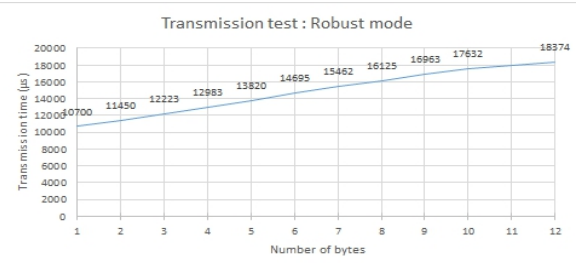


Fig. 7. baud-rate for Robust transmission

voltage batteries. These new cars could be fully integrated into our DC micro array architecture

#### IV. PLC BASED ON CANOPEN APPLICATION LAYER

In this section we present our second layer model of communication over DC powerline based on CAN bus (Control Area Network -ISO 11898) and CANOPEN as application Layer. In fact, in the state of art we have identified some commercial products that could be used for our smart grid architecture, among these modules, we've find out a transceiver (DCAN500) that is mostly used in communication between vehicle's modules over the battery's powerline. The DCAN500 transfers CAN messages over DC Power Line at bitrates up to 500Kbps using the DC BUS Technology. The DCAN500 operates as a transceiver for a new CAN physical layer over common DC power line used for network communication between all electronic modules on the BUS. The new physical layer eliminates the traditional CAN twisted pair data wires, saves weight and simplifies installation. The DCAN500 transmits and receives CAN2.0A/B messages. The arbitration over the DC bus is based on the CAN message Identifier's first 11 bits. The device operates with a 5MHz as Channel frequency and data is error protected QPSK modulated with low voltage narrow band carrier, eliminating as well the EMC generated by the "square wave" CAN data lines.

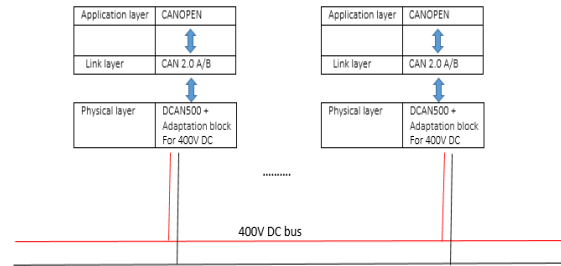


Fig. 8. Communication over dc bus based on CANOPEN

A node of this architecture must be composed of a micro-controller which owns the CAN device and whose resources are sufficient to support the CANOPEN application layer.

The main reason for choosing CANOPEN is the different and usefull services provided by this protocol which are well adapted to our application for the smart grid. CANOPEN uses

the notion of OD (object directory) in which an image of different variables of each node on the network is exposed for the other nodes and like that each smart node in our architecture will have a copy of OD of others smart nodes which favors our decentralized approach to energy management. CANOPEN also uses a synchronization and network management mechanisms which allows to our smart nodes to be synchronized in real time. Another positive point of CANOPEN is the use of an emergency mechanism by using high priority messages. This mechanism can be used in the event of a fault in our smart grid.

### A. Tests

In order to test the CANOPEN protocol for a micro grid application, we have designed a small scenario including one photovoltaic panel, one LED panel lighting and battery.

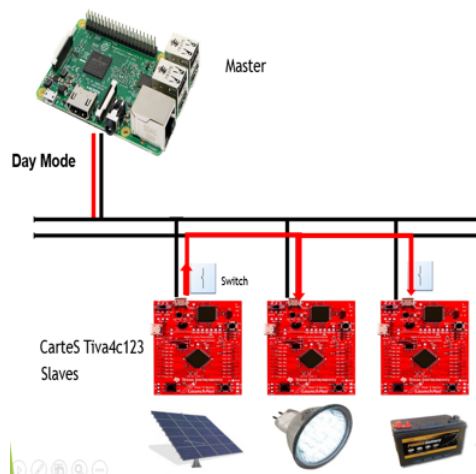


Fig. 9. Communication over dc bus based on CANOPEN

In this part, we will explain a basic application for our micro grid as well as how a node should work globally without going into the technical specification. A "node" manages the production of the PV solar panel and charges the battery in day mode, the node also controls the power of the battery to power the LED and manages the consumption in night mode. 2 Day and Night modes are shown in Figures 21 and 22.

The development of these two operation modes is carried out in the application layer above the CANOPEN layer, by exploiting the different services provided by this protocol as: PDO: For synchronous and Asynchronous communication between slaves / master or slaves / slaves of the different variables of the application (Current and voltage supplied by the PV and by the storage battery). Heartbeat: we have integrated this service so that the master can automatically detect faulty nodes, so we used this principle to detect new slaves on the network and to be able to configure them by the master with SDO messages. SDO: The implementation of this service is essential in all configurable or dynamic CANOPEN devices.

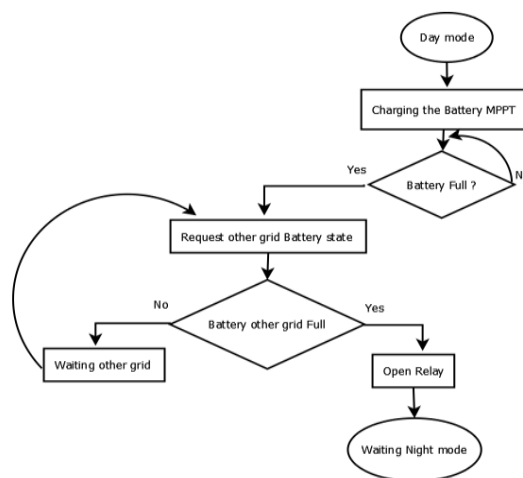


Fig. 10. Operation of a smart node in day mode

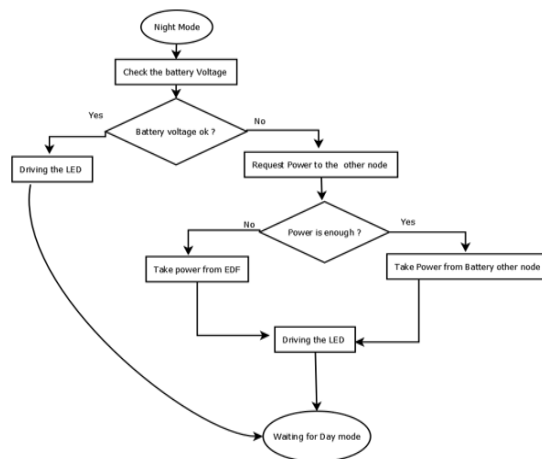


Fig. 11. Operation of a smart node in night mode

## CONCLUSION

PLC communication technology minimizes infrastructure and maintenance costs by communicating over existing power lines. With the release of open source protocols like G3-PLC, we could be able to design a communication models compatible with IP and used in such application of control/command for smart grid. We've also proposed a second PLC model of communication based on CANOPEN, The power of this protocol lies in its hyper-reliable and hyper-efficient mechanisms such as emergency messages, the automatic configuration of nodes on the network and the coexistence of two types of "synchronous and asynchronous" communication. Thus the existence of hardware components that allow communication on DC power lines makes this architecture very effective in the field of Smart Grid as well as in the automotive field and especially future electric vehicles.

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